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Design and evaluation of instructor-based and peer-oriented attention guidance functionalities in an open source anchored discussion system

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Social interactions to supplement learning and asynchronous tools to facilitate exchange of quality ideas have gained much attention in information systems education. While various systems exist, students have difficulty with deep processing of complex instructional materials (e.g., concepts of a theory and pedagogical support mechanisms derived from a theory). This research proposes a theoretical framework that leverages attention guidance in a social constructivist approach to facilitate processing of central domain concepts, principles, and their interrelations. Using an open source anchored discussion system, we designed a set of instructor-based and peer-oriented attention guidance functionalities involving dynamic manipulation of text font size similar to tag clouds. We conducted an experimental study with two small groups of first-year doctoral students in a blended-learning classroom format. Students in the control group had no access to attention guidance functions. Students in the treatment group used instructor-based attention guidance functionality and then switched to peer-oriented attention guidance functionality. The evaluation compared focus, content, and sequential organization of students' online discussion messages with heat maps, content analysis, sequential analysis, and statistical discourse analysis to examine different facets of the phenomenon in a holistic way. The results show that in areas where students struggle to understand challenging concepts, instructor-based attention guidance functionality facilitated elaboration and negotiation of ideas, which is fundamental to higher order thinking. In addition, after switching to peer-oriented attention guidance functionality, students in the treatment group took the lead in pinpointing challenging concepts they did not previously understand. These findings indicate that instructor-based and peer-oriented attention guidance functionalities offer students an indirect way of focusing their attention on deep processing of challenging concepts in an inherently open learning environment. Implications for theory, software design, and future research are discussed.

1. Introduction

Collaborative learning (CL) opens opportunities for an individual to actively construct new knowledge for a deep understanding of a subject matter. A key element in the effectiveness of this popular educational approach is social interaction (Phielix, Prins, Kirschner, Erkens, & Jaspers, 2011). Social interaction can provide a natural setting for demanding cognitive activities such as externalizing one's own perspective, questioning collaborators' perspectives, negotiating differences in perspectives, and internalizing a refined perspective (Dehler,

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Bodemer, Buder, & Hesse, 2011). These activities allow students to use one another as a resource for collaborative learning. Thus, the effectiveness of collaborative learning relies on the quality of social interaction.

Computer-supported collaborative learning (CSCL) systems can facilitate and stimulate the production of high quality social interactions with their functional characteristics (Suthers, 2006). An annotation-based asynchronous online discussion system is one valuable CSCL tool for collaborative processing of academic texts. This system is sometimes referred to as anchored discussion because students' shared annotations directly link discussion threads to relevant context, affording greater coherence (Brush, Bargeron, Grudin, Borning, & Gupta, 2002; Guzdial & Turns, 2000; Van der Pol, Admiraal, & Simons, 2006). There are two linking functions crucial to the design of an anchored discussion system: artifact-to-discussion linking and discussion-to-artifact linking. Suthers (2001) reported that these linking functions tightly couple instructional material (artifact) and its related discussion. Extensive prior research compared anchored discussion with conventional threaded discussion. For example, Guzdial and Turns (2000) showed that linking a discussion thread to an entire or a section of an instructional material stimulates more sustained and on-topic social interaction. Brush et al. (2002) obtained similar results and further demonstrated that linkage to finer-grained material (words or passages) promotes focused messages. Next, Mühlpford and Wessner (2005) found that these linking functions act as a catalyst for building common ground in social interaction. Along this line, Van der Pol et al. (2006) observed that an anchored discussion system increases communicative efficiency, encourages re-reading of relevant passages from an instructional material, and produces meaning-oriented discussion. Finally, Eryilmaz, Ryan, Van der Pol, Kasemvilas, and Mary (2013) isolated the combined effects of two linking functions from the presence of instructional material in an anchored discussion system and developed a theoretical model to explain the resulting quality and flow of social interactions.

Despite the positive results obtained by previous research, there are still many problems concerning the collaborative processing of academic texts with anchored discussion systems. A pressing problem, as stressed by Peters and Hewitt (2010), is that students have difficulty with deep processing of central domain concepts, principles, and their interrelations from complex instructional materials (e.g., concepts of a theory and pedagogical support mechanisms derived from a theory). The factors that give rise to this problem are twofold. First, students may opt for sharing existing opinions and experiences in online discussions due to a natural tendency to get things done with minimal effort (Sandberg & Barnard, 1997). In this line of reasoning, Hewitt (2005) found that students gravitate to familiar (comfortable) topics and avoid challenging topics from complex instructional materials in order to meet online discussion participation requirements. According to Bétrancourt, Dillenbourg, and Clavien (2008), students' above mentioned tendencies induce a "shallow processing of the subject matter instead of a deeper and more demanding processing" (p. 66). Along this line, Van der Pol et al. (2006) referred to shallow processing as "opinion-oriented discussion" and deep processing as "meaning-oriented discussion" within an anchored discussion system. Second, Kim and Hannafin (2011) found that when students have low levels of prior knowledge, naïve assumptions situated in prior experiences limit or fail to adequately inform their collaborative knowledge construction. Under such conditions, Kim and Hannafin (2011) remarked that "students develop robust and oversimplified misconceptions that prove highly resilient to change" (p. 412). Taken together, both factors underscore students' difficulties in productive use of instructional resources during anchored discussions, which can yield lower learning results (Jeong & Hmelo-Silver, 2010). Building on this line of reasoning, we concur with Lin and Atkinson (2011) that students with low levels of prior knowledge can benefit from attention guidance in collaborative processing of challenging concepts from complex instructional materials. However, a central challenge with attention guidance is that as students become more familiar with a subject matter, instructor's guidance may become redundant and in some cases it may even hinder collaborative knowledge construction because students may rely too much on an instructor's expertise and authority (Puntambekar & Hubscher, 2005). Therefore, the notion of successful scaffolding entails the fading of an instructor's guidance, which forces students to practice their own knowledge and develop the necessary skills for novel situations (Wecker & Fischer, 2007).

In order to address the problem at hand, we examined the design and evaluation of two different attention guidance functionalities in an open source anchored discussion system: instructor-based and peer-oriented attention guidance. Our central argument involved two components. First, instructor-based attention guidance functionality would help students with low prior domain knowledge to select and subsequently process a complex instructional material's challenging concepts with high quality social interaction patterns. Second, students would continue to carry out high quality social interaction patterns focusing on challenging concepts after switching from instructor-based to peer-oriented attention guidance functionality.

The article proceeds as follows. The next section leverages attention guidance in a social constructivist perspective to facilitate focused online learning conversations. Building on this theoretical framework, the subsequent section describes the design of instructor-based and peer-oriented attention guidance functionalities in an open source anchored discussion system. The sections following that detail the research hypotheses, methodological approach, and present results of the study. The article concludes with a discussion of the findings, contributions, limitations, as well as avenues for future research.

2. Theoretical framework

The theoretical lens that guides our study is an "interactional constructivist epistemology" (Suthers, 2006). This position emphasizes that the value of social interaction lies in "idea improvement" (Scardamalia & Bereiter, 2006, p. 99) within small learning groups. Two theoretical stances that were introduced by Mayer and colleagues (e.g., Robins & Mayer, 1993) serve as the underpinning of this position: active responding and active processing. The first stance, active responding, recognizes the value of making intellectual advances in areas where students struggle to understand, such as expressing ideas to clarify misconceptions; asking thought-provoking questions to pursue a new line of reasoning; elaborating on existing ideas to extend what is already known; and negotiating conceptual discrepancies to justify, defend, and revise ideas (Kobbe et al., 2007). The second stance, active processing, classifies these types of social interaction activities as constructive or truly mathemagenic (Rothkopf, 1970) only if their outputs contain ideas that go beyond the explicitly presented information in a complex instructional material (Chi, 2009). For example, asking students to compare-and-construct the abstract knowledge of two complex instructional materials in social interaction requires them to express the relevant similarities and differences in their own words when the instructional materials do not explicitly state this information. In summary, the term active characterizes the production of such activities in social interaction rather than passive acceptance of peers' inputs, and these actives become constructive when they produce new ideas that go beyond the information provided in a complex instructional material.

However, learning from social interaction may be hindered when students feel overwhelmed with the discovery of a new knowledge that no one in discussion yet possesses and the participants resort to shallow processing strategies in a computer-supported collaborative learning (CSCL) environment, a phenomenon typically referred to as lost in hyperspace (Scheiter & Gerjets, 2007). Under such conditions, prior research reported that online discussions drift from one familiar topic to another, while leaving important threads to die without diagnosing and resolving challenging misconceptions (Eklundh & Rodriguez, 2004; Hewitt, 2005; Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2003; Potter, 2008). As a result of this neglect, these discussion threads read more like reflective monologues than dialogical interactions (see Pena-Shaff & Nicholls, 2004 for a study that involves both undergraduate and graduate level students). The crucial point of this problem, as demonstrated by Engelmann and Hesse (2011), is that when misconceptions remain undiscovered students fail to grasp important information. This problem is especially important when research on the effects of collaborative learning is highly inconclusive (see Kirschner, Paas, & Kirschner, 2009; Phielix, Prins, & Kirschner, 2010 for reviews). In pursuing our research on the design and evaluation of CSCL systems, we build on Renkl and Atkinson (2007) to argue that students' active processing should not only relate to learning contents, but also focus on central domain concepts and principles that impact learning more directly. For example, in the subject of constructivist instruction, such concepts and principles may include relating teacher actions in a constructivist classroom to student learning and developing students' metawareness of their own understanding and learning processes.

Attention-guiding cues have the potential to focus students' attention to challenging concepts from complex instructional materials. We define attention-guiding cues as the manipulation of visuospatial characteristics (e.g., font size) of text-based instructional materials in order to capture students' attention in an involuntary or obligatory fashion. This exogenous cueing method with origins in text-processing research therefore does not add extra content information or change the existing content of complex instructional materials (De Koning, Tabbers, Rikers, & Paas, 2010a; Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009). A large body of research has demonstrated that for students with low prior domain knowledge, attention-guiding cues are an effective means of selecting challenging concepts from complex instructional materials. To begin, Lorch and Lorch (1995) found that visual cues slow the reading times for text processing. In line with this finding, De Koning, Tabbers, Rikers, and Paas (2010b) showed that visual cues facilitate students to look more often and for longer periods of time at cued than non-cued contents (for similar findings see Schnotz & Lowe, 2008). Furthermore, Irwin, Colcombe, Kramer, and Hahn (2000) remarked that students look at cued contents first even if they are no more important than non-cued contents. In terms of efficiency, Kalyuga, Chandler, and Sweller (1999) demonstrated that visual cues promote efficient learning as they decrease perceived difficulty of finding challenging concepts, which increases the availability of group time to collaboratively process those concepts. Taken together, the findings from these previous studies suggest that attention-guiding cues offer students an indirect way of focusing their social interaction on the processing of challenging concepts from complex instructional materials.

But, does attention guidance improve learning performance in a systematic way? On the one hand, Boucheix and Lowe (2010) showed that attention guidance supports construction of a mental model of causal chains in cued areas. Similarly, De Koning, Tabbers, Rikers, and Paas (2007) found that attention guidance improves retention and transfer performance. On the other hand, Kriz and Hegarty (2007) failed to find better learning outcomes for cued compared to non-cued instructional resources. In other words, cues may help students with locating specific information of an instructional material; however, cues do not necessarily help students with comprehension of information. As pointed by De Koning, Tabbers, Rikers, and Paas (2011), one possible explanation for this discrepancy is that cues are most beneficial for learning when instructional materials have high complexity because quickly locating challenging concepts increases the remaining available time for collaboratively processing those concepts in online discussions (see Kirschner et al., 2009 for a similar argument). Another caveat, as noted by Lowe (2004), is that cues may prompt students to process information in isolated ways without addressing the overall aspects of a learning task. Thus, a central challenge in attention guidance is to introduce the support without destroying the exploratory and creative potential of collaborative knowledge construction. To move toward this direction, the following section will explain the design of two different attention guidance functionalities in an anchored discussion system.

3. Design of attention guidance functionalities

We designed three prototype software systems by further developing Van der Pol et al.'s open source annotation tool (2006). We employed this tool for two reasons. First, it has a user-friendly interface that provides a tight coupling between the instructional material and its related discussion without hindering the interaction among students (e.g., Eryilmaz, Alrushiedat, Kasemvilas, Mary, & Van der Pol, 2009; Eryilmaz, Van der Pol, Clark, Mary, & Ryan, 2010; Eryilmaz, Van der Pol, Kasemvilas, Mary, & Olfman, 2010). Second, this tool reduces explicit coordination activities during online social interaction and thereby availing students more time and effort for demanding knowledge construction activities that positively associate with individual learning outcomes (Eryilmaz, Van der Pol, Ryan, Clark, & Mary, 2013).

All three of the prototypes capitalize on Marginalia, an open source JavaScript program, for the fine-grained annotation of HTML pages. Marginalia allows users to create new annotations by selecting desired text with the mouse and then clicking on an annotation bar to the right of the instructional material. Additionally, Marginalia supports multiple annotations on desired text to maintain independent threaded discussions that focus on the same topic. The flexibility of the HTML interface allows inclusion of two new functional characteristics in all prototypes. These functional characteristics aim to provide a stronger link between the instructional material and its related discussion as this linkage leads to superior learning outcomes compared to systems that lack it (Eryilmaz, Van der Pol, et al., 2013). More specifically, the first functional characteristic lights up both the annotated text and corresponding threaded discussion in red when either element is under cursor. The second functional characteristic embeds a student's key idea or justification for making an annotation directly in the relevant context that elicited it by inserting a sticky message. Therefore, the second functional characteristic acts as a catalyst to distill students' key ideas when annotating instructional resources. Furthermore, each threaded discussion starts with a student submitted key idea, which focuses on a specific content to discourage topic drift. Subsequently, we marked the particular point of each threaded discussion with a student submitted key idea and marked peers' uptakes of an original key idea as statements in threaded discussions. The flipside of an interface design with sticky messages is that it may interfere with students' reading as the instructional material becomes cluttered with sticky messages. To solve this problem, we designed sticky messages to appear only under the cursor. In sum, all three prototypes promote context-based discussions for deep processing of complex instructional materials. However, they differ on the nature of the attention

guidance functionalities as described below. Importantly, attention guidance functionalities described below go beyond providing students annotated instructional materials in anchored discussions (Wolfe, 2008) because students still have to distill the key ideas on their own when annotating difficult passages from text.

3.1. Instructor-based attention guidance functionality

The first prototype (Fig. 1) includes an instructor interface to find a balance between offering students an inherently open learning environment where they can express their own ideas and steering them toward discussing challenging concepts from complex instructional materials (Kirschner, Sweller, & Clark, 2006). In this prototype, only the instructor dynamically alters text font size by selecting desired text with the mouse and then clicking on an importance bar to the left of the instructional material. Thus, the importance bar is not visible to students in this prototype. Font size as demonstrated in tag cloud research is an effective visual property to capture attention (e.g., Bateman, Gutwin, & Nacenta, 2008; Halvey & Keane, 2007; Lohmann, Ziegler, & Tetzlaff, 2009; Rivadeneira, Gruen, Muller, & Millen, 2007). Moving this line of research forward, the first prototype represents the importance of the presented information with a corresponding font size. The cascading style sheet of the first prototype includes two font sizes: default and big. On the one hand, the default font size (10px) represents a medium level of importance. On the other hand, the big font size represents a high level of importance determined by the instructor-based on the learning objectives of social interaction. In order to determine which big font size captures attention in an involuntary or obligatory fashion, we created several font sizes ranging from 11px to 25px. We did not go above 25px because of the limited real estate available in the margins of the learning material. To aid in the design specification stage, we asked a separate group of pilot study participants to identify and report the font size that exerted the most visual influence on their attention. Based on their input, we set the big font size to be 150% larger than the default font size.

3.2. Peer-oriented attention guidance functionality

The second prototype (Fig. 2) extends the availability of the aforementioned importance bar to students in order to stimulate a group decision-making process that seeks consensus on challenging concepts for subsequent context-based discussions. This difference points to a scaffold role rotation from instructor to students, in which students receive the benefit of additional points of view, but must also

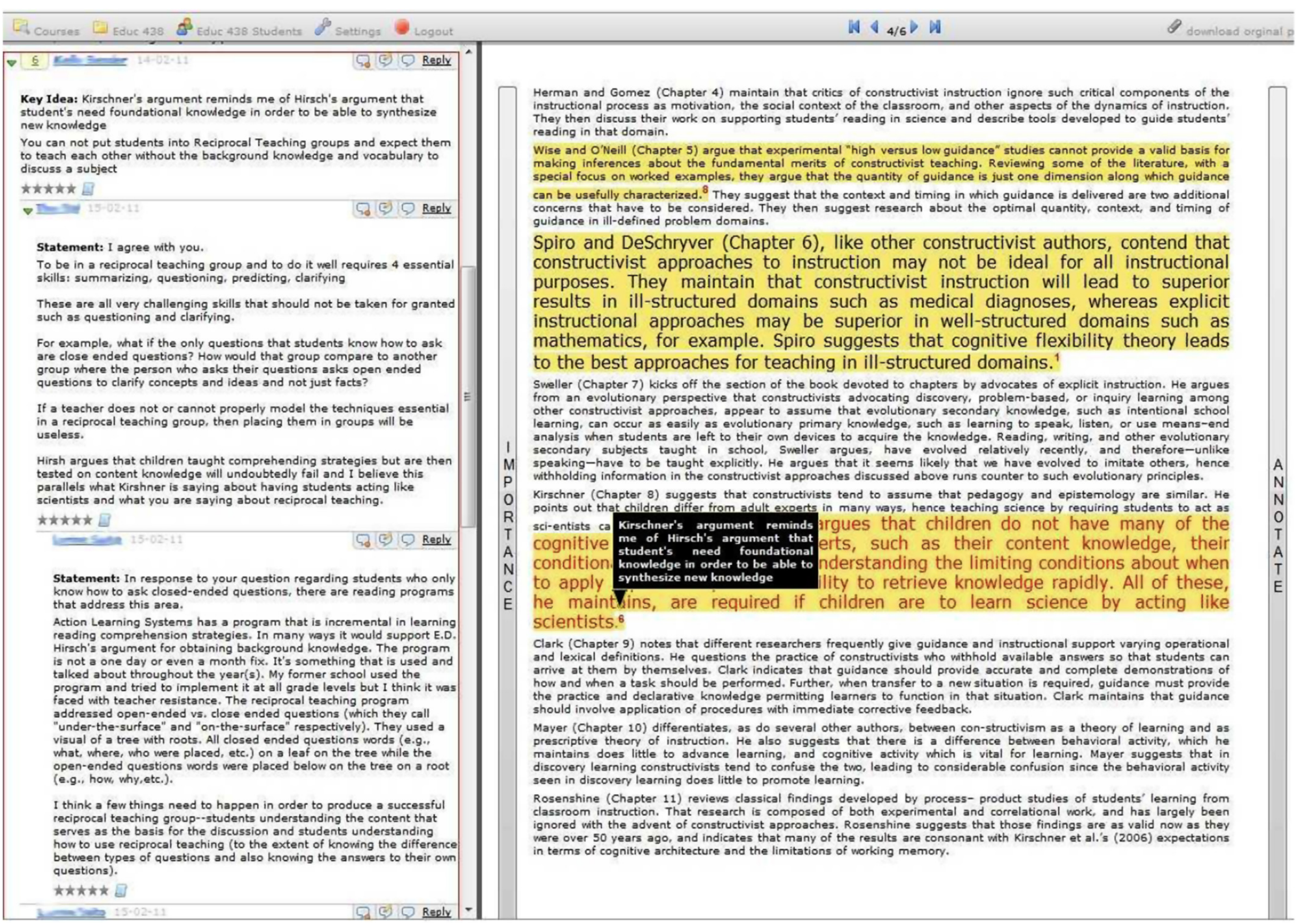

Fig. 1. Instructor-based attention guidance functionality (instructor's view). Note: importance bar is not available to students in this prototype.

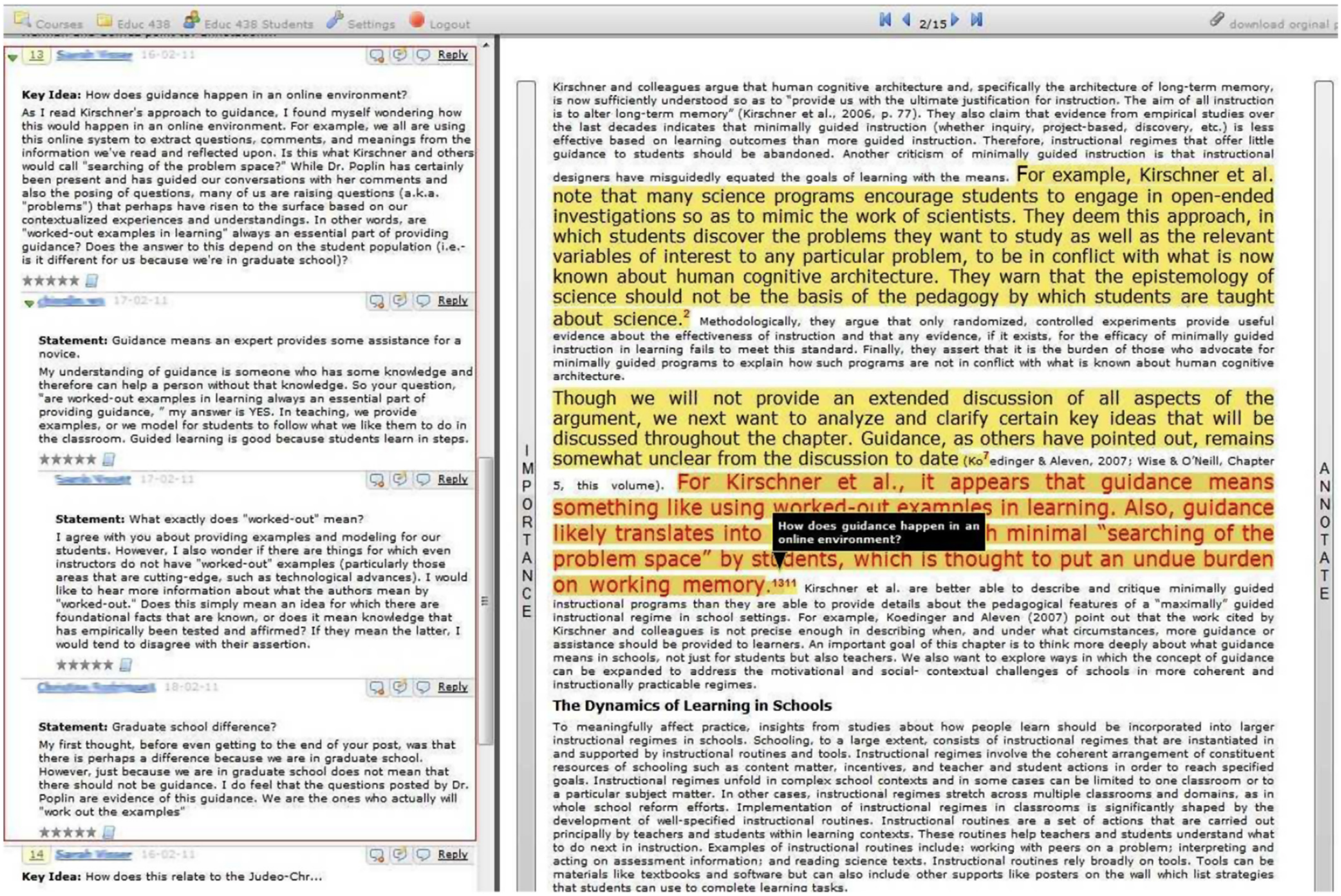

Fig. 2. Peer-oriented attention guidance functionality (student view).

compensate for the loss of the instructor's authoritative voice by more carefully assessing their peers' responses. The importance bar works in the same manner as the first prototype, except that the cascading style sheet now includes two big font sizes: big and bigger. The premise behind the bigger font size is to depict peer consensus on challenging concepts from complex instructional materials. When a student selects some text with the big font size marked by another student and clicks on the importance bar, the corresponding text gets marked with the bigger font size. In order to be consistent with the font size, we set the bigger font size to be 150% larger than the big font size. Due to the limited real estate available in the margins of the learning material, we did not allow unique student remarks to go above bigger font size. However, we recorded the number of unique student remarks on a piece of text with bigger font size in the database. Thus, the second prototype did not put a limit on unique student remarks. Furthermore, we designed the peer-oriented attention guidance functionality in a manner that prevented the same student from remarking a piece of text repeatedly and thus artificially inflating its importance. We took this approach to eliminate the risk of a single student biasing group's consensus on important areas.

3.3. Control software system

The third prototype (Fig. 3) is a regular system for anchored discussion that is enhanced with Marginalia Javascript program. This prototype serves as the control condition for testing the hypotheses of this study because it does not support attention guidance functionality. We now turn to our research questions and hypotheses.

4. Research questions and hypotheses

Despite the potential of attention-guiding cues for deep processing of challenging concepts from complex instructional materials, only few empirical studies exist in the CSCL literature about the effects of such support in online discussions (for a review see Wecker & Fischer, 2007). Furthermore, most studies do not provide direct evidence on students' perception of a complex instructional material's challenging concepts and the quality of collaboratively constructed knowledge focusing on those concepts (see Sereno, Shum, & Motta, 2005 for the design and evaluation of a rhetorical parser that assesses a document's important sentences by checking whether each of its words appears in the title, the headers, or the abstract). Drawing on the hefty cost of discovering a new understanding together that no one in discussion yet possesses and the positive learning outcomes facilitated by an earlier version of the relevant anchored discussion system (Eryilmaz, Van der Pol, et al., 2013), this study tackles the following research questions and their accompanying hypotheses:

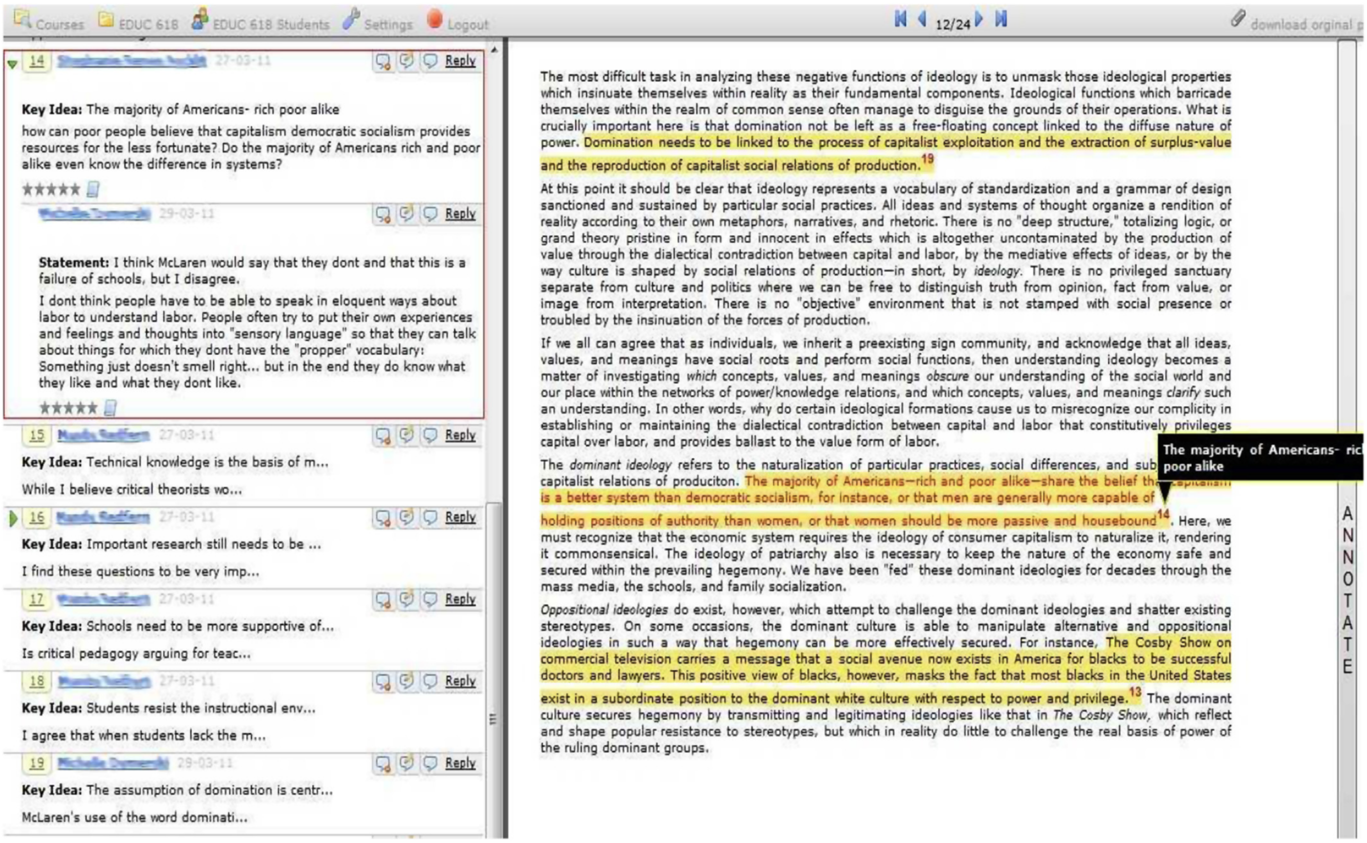

Fig. 3. Control software system.

I. How does an anchored discussion system's instructor-based attention guidance functionality affect collaborative knowledge construction focusing on challenging concepts from complex instructional materials?

Collaboratively constructing new knowledge that impacts learning more directly entails selecting challenging concepts from complex instructional materials that subsequently serve as the focus of intellectual advances in areas where students struggle to understand. For example, in the subject of constructivist instruction, such concepts and principles may include breaking down instruction with the intention of allowing students to more easily understand the content and guiding students through a series of small steps, carefully fit together, to the appropriate discoveries ("Aha!" experience). CSCL research on constructivist learning has repeatedly shown that students with low prior domain knowledge need guidance allowing them to learn challenging concepts more effectively and efficiently in complex domains (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner et al., 2006). We consider the instructor-based attention guidance functionality as instructional scaffolding for students with low prior knowledge in order to steer them toward discussing challenging concepts in an open learning environment. Furthermore, students may also challenge an instructor's views in this form of guidance, which we find positive. For instance, a student may post "I do not see why this matters", which leads to further negotiations. Thus, we hypothesize:

H1a: Instructor-based attention guidance functionality in anchored discussion system will facilitate students' selection of challenging concepts from complex instructional materials.

If a collaborative knowledge construction task must be finished within a certain time-limit, then the time dedicated to sharing existing opinions and experiences reduces the time available for diagnosing and resolving challenging misconceptions from complex instructional materials. Furthermore, when students gravitate to familiar (comfortable) topics, online discussions tend to branch and progressively become more incoherent (Hewitt, 2005; Lipponen et al., 2003; Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008). The coherence problem undermines the educational value of collaborative knowledge construction as students engage into many parallel conversations, not all of which necessarily focus on areas where they struggle to understand. Students' difficulties with preserving the interactional coherence of online discussions are understandable because everything may look important to them when they try to make sense of a complex instructional material (see Foss, 1989 for a similar argument). Thus, systems that help students focus on challenging concepts can improve their social interactions and their learning. This leads to the following hypothesis:

H1b: Instructor-based attention guidance functionality in an anchored discussion system will increase the quantity or improve the patterns of collaborative knowledge construction activities focusing on challenging concepts from complex instructional materials.

II. After switching from an instructor-based to peer-oriented attention guidance functionality in an anchored discussion system, will students continue to engage in high quality social interaction patterns focusing on challenging concepts from complex instructional materials?

The underlying assumption of the foregoing argumentation is that an instructor's guidance can help students with low prior domain knowledge to learn challenging concepts from complex instructional materials. However, as students become more familiar with a subject matter, instructor's guidance may become redundant and in some cases it may even hinder collaborative knowledge construction because students may rely too much on an instructor's expertise and authority (Puntambekar & Hubscher, 2005). Therefore, the notion of successful scaffolding entails the fading of an instructor's guidance, which forces students to practice their own knowledge and develop the necessary skills for novel situations (Wecker & Fischer, 2007). Although fading is considered important within the scaffolding paradigm, empirical research results on the effects of fading are sparse and inconclusive (for a review see Bouyias & Demetriadis, 2012). The issue of fading becomes more challenging in computerized scaffolding because it requires designing dynamic software systems that provide adaptive support (Kim & Hannafin, 2011). We argue that if students with low prior domain knowledge internalize the learning task they are being helped to accomplish via an instructor-based attention guidance functionality, they will take the lead in pinpointing challenging concepts they did not previously understand via a peer-oriented attention guidance functionality. Thus, we hypothesize:

H2: After switching from an instructor-based to peer-oriented attention guidance functionality in an anchored discussion system, students will continue engaging in high quality social interaction patterns focusing on challenging concepts from complex instructional materials.

5. Method

The evaluation of the proposed attention guidance functionalities included two stages: a) pilot study conducted to determine which big font size captured attention in an involuntary or obligatory fashion, b) main study aimed to test the above hypotheses. Pilot study participants were 8 freshmen doctoral students (7 males and 1 female) from a blended-format seminar in information systems and technology research. The mean age of the pilot study participants was 25.74 years (SD = 2.36). The learning objective of this seminar was to introduce students to the community of information systems and technology research, its participants, the topics they investigate, and the approaches they use. Six discussion themes were run consecutively through the seminar for a period of one week each. These discussion themes were facilitated by the instructor-based attention guidance functionality. Each theme reflected a specific research article from the Management Information Systems Quarterly journal. At the end of each discussion theme, the main researcher conducted face-to-face interviews by asking pilot study participants the order through which they processed the contents of a learning material. The interviewees remarked that sentences with 150% larger font size "pop out" from their surroundings, which led interviewees to process them first, even if they were no more likely to be important than any other sentence.

The main study was a longitudinal experiment with two small groups: treatment and control. We specifically chose this granularity because it allowed a wide range of social interactions to play out while preventing us from losing track of them (Stahl, 2006). Students in the control group had no access to attention guidance functions. Students in the treatment group used instructor-based attention guidance functionality and then switched to peer-oriented attention guidance functionality. The longitudinal nature of the study provided the means for calibrating the guidance to students in the treatment group through ongoing diagnosis of online discussions. This ongoing diagnosis included two variables: topic of a message and activity performed within a message. Two independent coders who were blind to the study's purpose examined these variables after students completed each discussion topic. This approach, which underscores an advantage of small group experimentation (Stahl, 2006), allowed us to switch the treatment group from instructor-based to peer-oriented attention guidance functionality in order to test H2. Participants were 24 doctoral students (8 males and 16 females) from a blended-format seminar in Learning and Pedagogical Theories. The mean age of the students was 26.38 years (SD = 1.98). We randomly and equally assigned the participants to one of two groups. The learning material for both groups consisted of six topics from the *Constructivist Instruction: Success or Failure* book. These topics were arranged in the following sequence. Topic 1 was "The success or failure of constructivist instruction"; topic 2 was "Taking guided learning theory to school"; topic 3 was "Epistemology or pedagogy, that is the question"; topic 4 was "The empirical support for direct instruction"; topic 5 was "from Behaviorism to constructivism: a philosophical journey from drill and practice to situated learning"; and topic 6 was "Beyond the fringe: building and evaluating scientific knowledge systems." Each topic was covered during a two-week online discussion period in an inherently open learning environment. Participation in the online discussion was compulsory and represented 25% of the overall grade. The minimum participation requirement was to post two messages per topic and respond to at least two fellow students' messages for that topic. When using the peer-oriented attention guidance functionality, every student in the treatment group was additionally asked to use the importance bar at least once in order to collaboratively decide important ideas from text. The main body of gathered data included the transcripts of 12 online discussions. We describe below the methods of analyses used to test the hypotheses.

5.1. Analyzing students' selection of challenging concepts

Annotations as described by Yeh and Lo (2009) provide insight into the focus of students' attention on text. We calculated a selection ratio for each group's discussion topic by dividing student annotations on challenging concepts (e.g., designing learning activities that challenge students' current suppositions and distinguishing scientific claims from pseudoscience and hoax claims) to total student annotations. We used the first five discussion themes for the analysis of instructor-based attention guidance functionality. We computed summary statistics (mean, standard deviation) and tested for significant differences between the instructor-based attention guidance functionality and control condition with two-tailed t-tests and proportion tests (Kennedy, 2008). In light of our findings, we examined the effects of switching treatment group students from instructor-based to peer-oriented attention guidance functionality on the last discussion topic.

In order to verify the effectiveness of the proposed attention guidance functionalities, we constructed visual heat maps based on students' cursor movements during the course of six discussion topics (see Chen, Anderson, & Sohn, 2001 for a strong positive correlation between cursor movement and attention). The standardized heat maps employed ClickTale Web application's tracking code. We

incorporated the relevant code into an HTML interface, and ran each discussion topic's tracking for two weeks. The colors on the heat maps ranged from red to blue. Red color suggests the areas that received the most student attention; the yellow color suggests areas that received less student attention; and blue color suggests areas that received the least student attention during online discussions.

5.2. Analyzing students' discussion of challenging concepts

This study employed quantitative content analysis, sequential analysis, and statistical discourse analysis to gain insight into discussions focusing on challenging concepts that students struggle to understand. We adopted a coding scheme developed by Li and Huang (2008) to code online discussion messages. The unit of content analysis was each complete message posted in the online discussion because students' messages were rather short and mainly consisted of only one type of activity (see Eryilmaz, Ryan, et al., 2013 for a similar argument). Table 1 describes the coding categories with examples of raw data for each category.

We examined two-event sequences of threaded discussions with sequential analysis. A central underlying premise of this analytic framework is that messages in a threaded discussion are inherently interconnected and dynamically affect one another (Lu, Chiu, & Law, 2011; Suthers, Dwyer, Medina, & Vatrapu, 2010; Wise & Chiu, 2011). Thus, a message within a threaded discussion can only be fully understood by examining its micro-context of preceding messages (Chiu, 2008). We used a discussion analysis tool (DAT) developed by Jeong and Frazier (2008) to analyze two-event sequences in threaded discussions. DAT offers two metrics. The first metric, a transitional state diagram, provides an overview of the flow of interaction patterns. DAT calculates transitional probabilities by tallying the frequency of responses for each message type. The second metric, mean response scores, computes the relative frequency of each type of message eliciting a particular type of response. Thus, the second metric is well suited for comparing the differences between probabilities of transitions.

However, a limitation with two-event sequence analysis of threaded messages as noted by Suthers et al. (2010) is that it models a current message based on one previous message, even though a message may depend on a cumulative series of immediately preceding messages (see Zemel, Xhafa, & Cakir, 2007 for a similar argument). To address this limitation, we conducted a statistical discourse analysis (SDA) (Chiu, 2008) to examine longer sequences of threaded messages. Statistically analyzing social interaction processes involves difficulties regarding the dataset, outcome variables, and exploratory variables. SDA (Chiu, 2008) addressed these issues. We use Markov Chain Monte Carlo multiple imputation (MCMC-MI) to estimate the values of the missing data, which addresses this issue more effectively than deletion, mean substitution, or simple imputation according to computer simulations (Peugh & Enders, 2004). SDA addresses the outcome issues (nested data, time, discrete, infrequent, multiple outcomes) with multilevel analysis (Goldstein, 1995), an I^2 index of Q-statistics (Huedo-Medina, Sánchez-Meca, Marin-Martinez, & Botella, 2006), Logit, Logit bias estimation (King & Zeng, 2001) and a multivariate outcome model (Goldstein, 1995). SDA addresses the explanatory variable issues (sequences, context-dependent effects, indirect effects, false positives) with a vector auto-regression (VAR, Kennedy, 2008), multilevel random effects, multilevel M-tests (MacKinnon et al., 2004) and the two-stage step-up procedure (Benjamini, Krieger, & Yekutieli, 2006).

5.3. Analyzing control variables

We included prior knowledge and task complexity as the most important control variables in our study (a thorough discussion of a wide variety of factors is beyond the scope of this article see Kirschner, Martens, & Strijbos, 2004 for complex set of cognitive, motivational, and social factors). Empirical research focusing on conceptual change induced by text reading has shown that students' prior knowledge affects how they interact with the instructional materials (Ozuru, Dempsey, & McNamara, 2009). Particularly pertinent here is that high prior knowledge can facilitate the cognitive processing of reading (Wolfe & Goldman 2005). In contrast, low topic knowledge often confounds students' best efforts to understand text accurately (Sinatra & Mason, 2008). Before participating in the learning activities, each student's prior knowledge of the subject domain was assessed with an open-ended question: "Briefly describe inquiry-based constructivist instruction in information systems and technology education. What are the strengths and weaknesses of engaging students in open-ended investigations? Provide reasoning for each strength and weakness." To answer this question, each student had 20 minutes to write a short reflective essay alone without consulting any resources. Using an essay coding framework developed by Jamaludin, Chee, and Ho (2009), two trained coders independently scored each essay from 0 to 12 points without knowing each student's assigned condition.

Table 1
Coding schema.

Category	Description	Example
Sharing	Presenting an initial interpretation of learning material	*I think the author aims to strengthen the argument for a systematic pattern of direct instruction as a primary tool for effective teachers by differentiating between epistemology and pedagogy.*
Questioning	Discovering dissonance or inconsistency among ideas	*The question that kept arising for me from your message was whether or not this approach is a one-size-fits-all across various disciplines. This seems obvious to me when it comes to subjects like math, science, and reading, but I am intrigued by constructivist assertions that not all knowledge is task-based.*
Elaborating	Expanding ideas from earlier messages in a discussion thread	*I appreciate you bringing up the movement from novice to expert. My hunch is that somewhere along that journey, hands-on, practical experimentation becomes an important part of an expert's development of foundational knowledge.*
Negotiating	Comparing and contrasting different perspectives for a deeper understanding of learning material	*I would argue that mistakes are necessary in the process of discovery based learning because they become a further teaching opportunity: unraveling presuppositions by asking the right question, introducing new evidence, etc.*
Producing	Producing new ideas or explanations on topics where differences in perspectives existed	*Got it. On an elementary level there are curriculum books for teaching creativity. See critical thinking skills for grades 1–2 published by Evan-Moor. I just checked online and they renamed their series critical and creative thinking skills. I think creativity can be taught.*

The challenges of a learning task naturally influence the dynamics of online discussion. Previous research stressing the potential of this social interaction process shows that collaborative learning is more effective than individual learning for relatively complex tasks (Kirschner et al., 2009). However, a task that is too difficult can also undermine the social interaction process because students can get frustrated and lose their motivation (Timmers & Veldkamp 2011). Thus, similar to Vygotsky's (1978) concept of the zone of proximal development, an optimal task complexity lies just above what individual learners can accomplish alone. We operationalized task complexity by using a labeled six-point Likert-type subjective rating scale validated by Cierniak, Scheiter, and Gerjets (2009). The labels reached from 1 "Not at all" to 6 "Extremely." The question of the subjective rating scale was "How difficult was the learning task for you?" The rationale behind using a subjective rating scale is twofold. First, prior research has demonstrated that unobtrusive subjective rating scales are more sensitive to variations in instructional tasks than physiological measures (Paas, Van Merriënboer, & Adam, 1994). Second, subjective ratings as noted by Schnotz and Kürschner (2007) are simple and easily applicable in a natural setting, which increases the ecological validity of the findings.

6. Results

The presentation of the results follows the order of our hypotheses. First, we present the effect of instructor-based attention guidance functionality on selecting challenging concepts from complex instructional materials. Thereafter, we show the coding of students' posts and patterns in online discussions focusing on challenging concepts. Finally, we present the focus, coding, and sequential organization of the treatment group's online discussion after they switch from the instructor-based to peer-oriented attention guidance functionality.

6.1. Students' selection of challenging concepts

H1a predicted that instructor-based attention guidance functionality in an anchored discussion system would facilitate students' selection of challenging concepts from complex instructional materials. We computed a selection ratio of challenging concepts for each discussion topic. Table 2 shows that treatment group students had both a greater frequency of annotations focusing on challenging concepts, $t(8) = 3.11$, $p = 0.02$, $d = 1.97$, and a greater proportion of annotations focusing on challenging concepts, $z = 5.1$, $p < 0.001$, than the control group.

While the above statistical analysis tested whether students' selection of challenging concepts was differed significantly between the two groups, it did not provide information about how students viewed cued and non-cued passages from text. This important information complementary to statistical analysis is available through heat maps. The heat maps exposed that instructor's cues had an impact on the way students' attention was distributed in text. Fig. 4 presents a heat map derived from ten page views by ten different students in the treatment group. This heat map suggests that students paid the most attention to understanding difficult passages suggested by the instructor via big font size and sticky messages summarizing their own key ideas for annotating those passages, as indicated by the red color (in the web version).

Fig. 5 shows a heat map derived from eight page views by eight different students in the control group. A striking feature of this heat map is that students' attention was more widely distributed on a page, but less concentrated in any particular area, as indicated by the yellow and green colors (in the web version). This heat map also suggests that sticky messages that distill students' key ideas for making annotations received less attention when the entire text had the default font size. Taken together, these heat maps provide further support to H1a.

6.2. Discussing task-relevant information findings

H1b predicted that instructor-based attention guidance functionality in an anchored discussion system would increase the quantity or improve the patterns of collaborative knowledge construction activities focusing on challenging concepts from complex instructional materials. As noted before, the results of discussing challenging concepts from complex instructional materials incorporate two parts: classifying individual messages and examining sequential relationships in threaded discussions. The dataset for testing H1b included the transcripts of the first five discussion topics. Because of the potential for ambiguity in applying the coding scheme, a random sample of 36 messages (10% of the total) was selected for the training of two coders who were blind to our hypotheses. After the training exercise, a total of 448 messages were coded independently by each individual coder. The Krippendorff's alpha (2004) inter-rater reliability coefficient was 0.78 which exceeds 0.67 and indicates satisfactory agreement beyond chance. All disagreements between coders were resolved by discussion. Table 3 displays coding results at a discussion level according to the variables of interest.

Table 2
Selection ratio of challenging concepts for the first five discussion topics.

Condition	Discussion topic					
	1	2	3	4	5	Mean
Instructor-based attention guidance functionality						
Frequency of student annotations focusing on challenging concepts	9	12	10	7	14	10.4 (2.7)
Total number student annotations	14	17	12	9	19	14.2
Selection ratio of challenging concepts	64%	70%	83%	78%	74%	73%
Control software system						
Frequency of student annotations focusing on challenging concepts	3	8	6	5	7	5.8 (1.9)
Total number of student annotations	9	19	17	16	21	16.4
Selection ratio of challenging concepts	33%	42%	35%	31%	33%	35%

Note. Standard deviation in parenthesis.

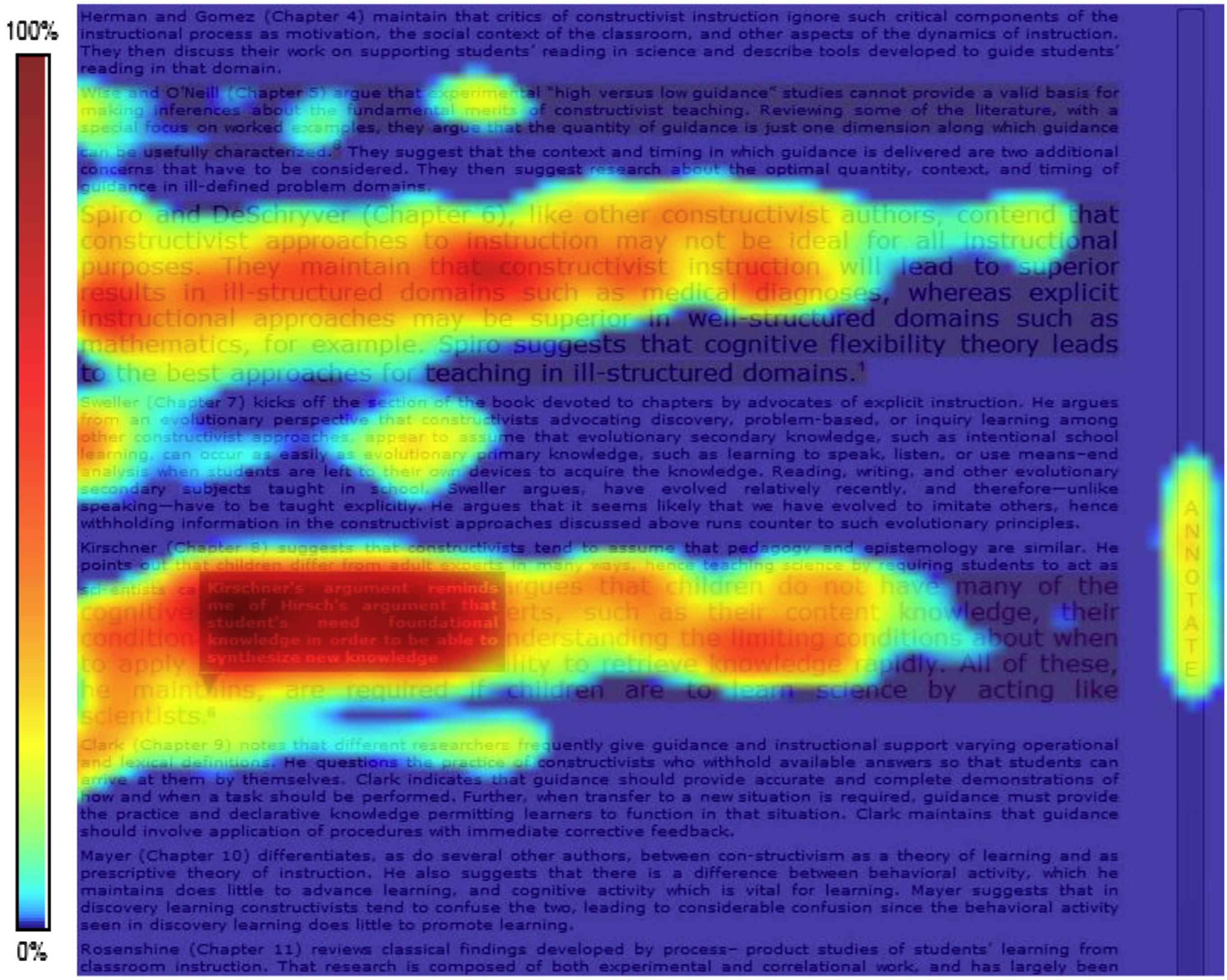

Fig. 4. Heat map for teacher-based attention guidance functionality.

We found that the treatment group had a higher proportion of task-related messages than the control group, $z = 5.43$, $p < 0.001$. Closer examination demonstrated that treatment group produced proportionally more questions, elaborations, and negotiations than the control group, with no significant differences in sharing or producing (see Table 3).

The above quantitative content analysis results served as a foundation for examining prevalent patterns of collaborative knowledge construction activities through two- and three-event sequences of students' messages in threaded discussions. Thus, the validity of sequential analyses results reported below tied directly to the validity of previous message categorization. For the first five discussion topics, the average discussion thread length for the treatment group was 2.93 (SD = 2.32), while the average discussion thread length for the control group was 4.16 (SD = 3.02), $t(88) = 2.16$, $p = 0.03$, $d = 0.46$. For the two-event sequence analysis, all 303 task-related messages (174 for the treatment group and 129 for the control group) underwent a series of sequential transition matrix calculations (Jeong & Frazier, 2008), resulting in Figs. 6 and 7, and Table 4. The circles in these figures represent the task-related messages, in accordance with the adopted coding scheme. The arrows between the circles depict directed transitions. The thickness of an arrow is proportional to probability of a transition. The values specified in the figures illustrate transitional probabilities. These probabilities are based on the frequency of a particular response posted in reply to a particular message category. For instance, a sharing message category was followed by an elaborating response 49% of the time with the instructor-based attention guidance functionality. To ease readability, transitional probabilities less than 0.1 were omitted in Figs. 6 and 7.

Table 4 reports descriptive statistics for the examination of two-event sequences in threaded discussions. There are three metrics in Table 4: sample size, mean, and standard deviation. The first metric, sample size, indicates the total number of times a particular response immediately follows a particular message category. As shown in Table 4, elaboration messages immediately followed sharing messages 64 times with the instructor-based attention guidance functionality. The second metric, mean, represents the mean number of a particular response posted in reply to a particular message category. For example, the mean number of elaboration messages posted in reply to each sharing message was 0.38 with the instructor-based attention guidance functionality. The last metric, standard deviation, expresses the variability among instances of a particular message category to elicit a specific response.

Fig. 5. Heat map for control software system.

We found that the students in the treatment group demonstrated significantly higher transitional probabilities from sharing to elaborating, $t(137) = 2.56$, $p = 0.01$, $d = 0.44$, and from questioning to negotiating, $t(84) = 2.76$, $p = 0.007$, $d = 0.63$, compared to control group students. To facilitate the explanation of these sequential patterns, we draw upon two discussion samples from the treatment group below. The first discussion sample (see Table 5) stems from “epistemology or pedagogy, that is the question” topic studied in the course. The starting point of this discussion presents student 7’s interpretation of the relationship between epistemology and pedagogy expressed through an analogy: “standards and knowledge drive instruction.” Student 12’s response to this message reflects a shared understanding of the core concepts: epistemology and pedagogy. Subsequently, student 12 moved student 7’s initial idea forward by articulating that “pedagogy is not one-size-fits-all.”

Table 3
Content analysis of first five discussion topics.

Messages		Instructor-based attention guidance functionality		Control software system		z	p
		Frequency	Proportion	Frequency	Proportion		
Task-related	Sharing	66	0.30	76	0.33	0.68	0.50
	Questioning	52	0.24	36	0.16	2.12*	0.03
	Elaborating	30	0.14	11	0.04	3.73***	<0.001
	Negotiating	23	0.11	5	0.02	3.90***	<0.001
	Producing	3	0.01	1	0.004	0.77	0.44
	Total task-related	174	0.80	129	0.56	5.43***	<0.001
Non task-related		43	0.20	102	0.44		
Total		217	1.00	231	1.00		

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

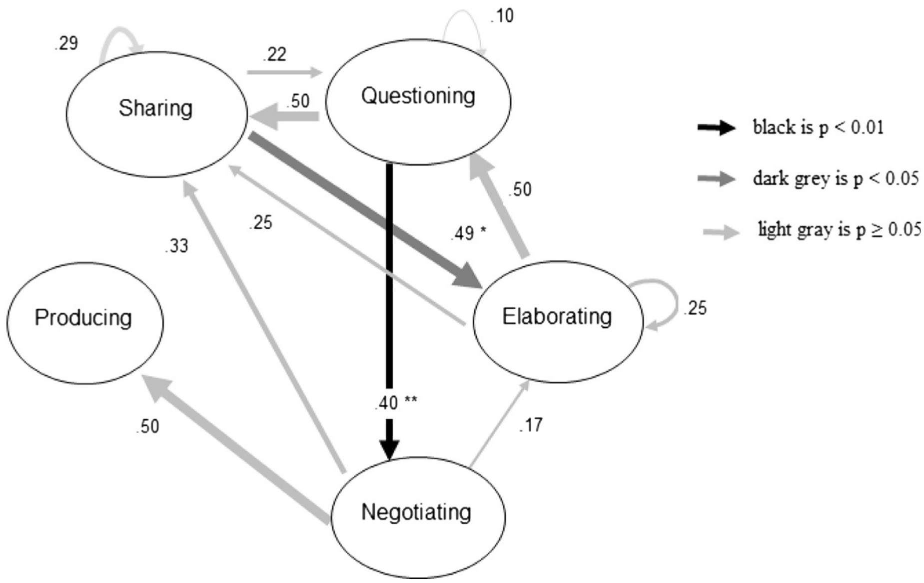

Fig. 6. Transitional state diagram for treatment group $^{*}p < 0.05$; $^{**}p < 0.01$. Note: transitional probabilities less than 0.1 are omitted.

The second discussion sample (Table 6) stems from "the empirical support for direct instruction" topic studied in the course. The beginning of this discussion underscores student 1's confusion from text, which raises two though-provoking questions on the concept of "process-product." An attempt to answer these questions comes from student 8 whose argumentation centers on learning goals in order to examine explicit instruction and constructivist methods in information systems education. Consistent with student 1, student 8 highlights a knowledge gap at the end of message number 90 to invite further negotiation on this complicated topic.

As mentioned before, we assessed group differences in three-event sequences within threaded discussions by using SDA (Chiu, 2008). Consistent with the above analyses, we found that the treatment group was more likely than the control group to elaborate. Likewise, consistent with the sequential analysis, sharing was often followed by elaboration and questioning was often followed by negotiation. Furthermore, elaborations were less likely in later discussions, and students scoring high on the negotiation survey were more likely to negotiate (evidence of the negotiation survey's validity). Concerning the analysis of three-event sequences, a common three-event sequence in both groups was uncovered: sharing (−2) → question (−1) → negotiation (0) (Odds Ratio, 6.52, $p < 0.05$). However, we found no statistically significant group differences in three-event sequences by using this procedure. Fig. 8 portrays SDA findings.

In summary, the results showed that students with access to instructor-based attention guidance functionality displayed more questioning, elaborating, and negotiating in their messages compared to students in the control group. Moreover, sequential analysis results show two significant transitional probabilities in relation to task-related messages: sharing to elaborating and questioning to negotiating. The SDA results are consistent and also show a common three-event sequence in both groups: sharing (−2) → question (−1) → negotiation (0). Taken together, these results only partially support H1b.

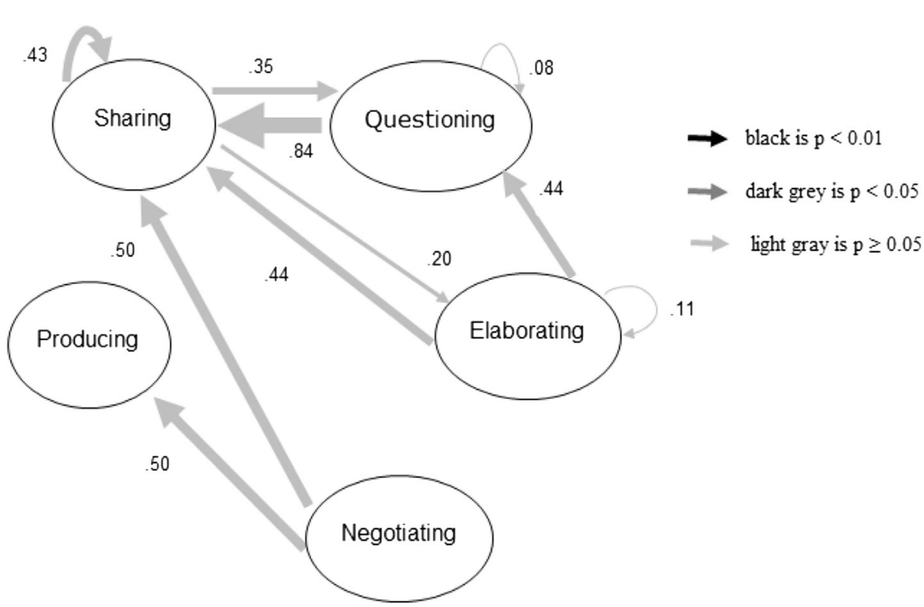

Fig. 7. Transitional state diagram for control group $^{*}p < 0.05$; $^{**}p < 0.01$. Note: transitional probabilities less than 0.1 are omitted.

Table 4
Descriptive statistics of two-event sequences in threaded discussions.

Condition	Two-event sequences					
	Sharing → elaborating			Questioning → negotiating		
	n	*M*	SD	*n*	*M*	SD
Instructor-based attention guidance functionality	64	0.38	0.74	49	0.43	0.73
Control software system	75	0.13	0.38	37	0.08	0.28

6.3. Switching from teacher-based to peer-oriented attention guidance

H2 predicted that students who switched from the instructor-based to peer-oriented attention guidance functionality would continue to carry out high quality social interaction patterns focusing on challenging concepts from complex instructional materials. Table 7 shows the differences in students' selection behaviors during the last discussion topic.

In the last discussion topic, treatment group's frequency (11) and proportion (69%) of annotations focusing on challenging concepts using peer-oriented attention guidance functionality did not differ significantly from their means over the first five discussions (10.4 and 73%), $z = 0.32$, $p = 0.75$, showing support for the fading hypothesis. As before, the treatment group had a larger frequency and greater proportion of annotations focusing on challenging concepts than the control group (6 and 29%, $z = 2.42$, $p = 0.02$). Building on Tables 2 and 7, Fig. 9 demonstrates consistent patterns between the five earlier discussions and the sixth discussion, showing that the fading of the instructor's guidance did not sharply reduce the treatment group's annotations focusing on challenging concepts from complex instructional materials.

Fig. 10 portrays a heat map derived from nine page views by nine different students in the treatment group when they switched from the instructor-based to peer-oriented attention guidance functionality. The heat map for peer-oriented attention guidance functionality reveals a concentrated attention around a sticky message on bigger font size text. This heat map suggests that the key idea posted by a student for annotating this passage reflects a shared misconception by eight other students who invest an effort into developing a better understanding of the passage, as indicated by the red color (in the web version).

Two coders independently coded a total of 85 messages from the last discussion topic. The Krippendorff's alpha (2004) inter-rater reliability coefficient was 0.81, showing satisfactory reliability. All disagreements between coders were resolved by discussion. Table 8 displays coding results at a discussion level according to the variables of interest.

Statistical tests showed that none of the frequencies or proportions for any type of message or message totals differed significantly between instructor-based and peer-oriented attention guidance functionalities, showing that fading instructor's support did not significantly reduce the treatment group's task-related messages and supporting H2. In the sixth discussion, there was no statistically significant group difference in task-related message categories. Moreover, there was no statistically significant difference between these two groups for their two- and three-event message sequences.

6.4. Control variables findings

The Krippendorff's alpha inter-rater reliability measure for the coding of the prior knowledge test was 0.75, which indicates satisfactory agreement beyond chance. Table 9 presents the descriptive statistics of the prior knowledge test. There was no statistically significant difference between the treatment and control groups with regard to the prior knowledge test, $t(22) = 0.19$, $p = 0.85$, $d = 0.26$.

Table 10 shows the descriptive statistics and independent *t*-test results for task complexity of six consecutive discussion topics. Based on Table 10, there was no statistically significant difference between the treatment and control groups with regard to task complexity in six consecutive discussion topics.

7. Discussion

With the increasing use of CSCL systems, it is timely and important to understand how to engage students in productive collaborations with their classmates (Suthers, 2006). Therefore, this study examined the design and evaluation of two different attention guidance

Table 5
Extraction of an actual discussion sample representing sharing-elaborating sequence.

Student Annotated text	MessageID	Author	Content	Code
The "only" relationship between epistemology and pedagogy is based not upon the translation or mapping of an epistemology (on) to a pedagogy, but rather the selection of a fitting pedagogy to "teach" (i.e., help the learner acquire) the epistemology. In other words, the choice of a pedagogy can and possibly must be "informed" by the epistemology that the learner should acquire, but is not the same as making use of that epistemology as a pedagogy.	74	Student 7	*I think the author's point is that epistemology informs pedagogy in the same way that standards and knowledge drive instruction. "The epistemology that the learners must acquire" implies a body of knowledge to me that must be pondered by a teacher prior to designing instruction to transmit what must be learned.*	Sharing
	75	Student 12	*Yes, epistemology is the subject matter knowledge. Any teacher needs to have the subject matter knowledge in order to perform his or her job. The next step is to transfer this knowledge to students. I would add here that even when teachers have pedagogy, it still does not fully prepare them for the "real" challenges/situations of diverse populations because no one pedagogy is a one-size-fits-all.*	Elaborating

Table 6
Extraction of an actual discussion sample representing questioning-negotiating sequence.

Student Annotated text	MessageID	Author	Content	Code
The goal of the process-product research on instruction was to identify the instructional procedures that were used by those teachers whose students made the highest gains on standardized tests or tests developed by the research team and to compare these instructional procedures with the procedures used by those teachers whose students made the smallest gains on the same tests.	89	Student 1	*I do not have clear understanding of "process-product." Does it mean that if a prescribed procedure (a process) is followed, the result (product) will be the same? Is this a cookbook approach to student achievement?*	Questioning
	90	Student 8	*I am also having hard time with this. My take is that depending on the content, the students, and the context, as the instructor I choose what seems to be the best. For me, explicit instruction does fit at times. Inquiry and constructivist methods also find a place. It really depends on the learning goal…but I guess if I'm the one deciding then it really isn't constructivist at all, is it?*	Negotiating

functionalities in an open source anchored discussion system. In this section, we discuss why the proposed functionalities led to three important results and then tie each result to the theoretical framework.

First and foremost, the results showed that instructor-based attention guidance functionality in an anchored discussion system facilitated students' selection of challenging concepts from complex instructional materials. Concerning software design, this result emphasizes the strong positive effect of font size on capturing students' attention and is in accordance with tag cloud research (e.g., Bateman et al., 2008; Halvey & Keane, 2007; Lohmann et al., 2009; Rivadeneira et al., 2007) that demonstrates how tags with large font sizes stand out to viewers. Complementing this result, the qualitative analysis of heat maps suggests that instructor's suggestions encouraged students with low prior domain knowledge to express their misconceptions of difficult passages via sticky messages on text and these sticky messages generated a concentrated group effort to develop a better understanding of those passages. To our knowledge, the heat maps presented here provide initial insights into students' attention allocations and transformation during online discussions. These findings offer a natural solution to the critical problem of finding a balance between offering students an inherently open learning environment where they can express their own ideas and steering them toward discussing challenging concepts from complex instructional materials (Kirschner et al., 2006). Furthermore, these findings go beyond providing students annotated instructional materials (Wolfe, 2008) because students still have to distill the key ideas on their own when annotating difficult passages. In light of these findings, we argue that the utility of proposed instructor-based attention guidance functionality lies in the continuous assessment of students' attention allocations, its interpretation (diagnosis), and the calibration of the guidance when needed. With respect to our theoretical framework, these findings confirm that students with low prior domain knowledge need guidance (Hmelo-Silver et al., 2007; Kirschner et al., 2006) allowing them to focus on areas where they struggle to understand (Renkl & Atkinson, 2007). A possible explanation for our findings is that most of the information seemed new to students with low prior domain knowledge and the visual cues reduced students' search activity. As shown by the heat maps (Figs. 4 and 5), the control group students searched for central domain concepts and principles (yellow and green, in the web version, regions in Fig. 5), while the treatment group students were trying to understand the conveyed messages in cued areas (red, in the web version, regions in Fig. 4).

Second, our results indicate that instructor-based attention guidance functionality in an anchored discussion system increased the quantity of questioning, elaborating, and negotiating messages and improved two transitional probabilities in relation to these messages: sharing to elaborating and questioning to negotiating. Importantly, the statistical discourse analysis results corroborated that the treatment group was more likely than the control group to elaborate, showing that the result at hand is especially robust. These results suggest a solution to the problem of collaborative discovery of new knowledge that one in discussion yet possesses (Peters & Hewitt, 2010). Particularly, the two-event sequences identified in Table 4 are similar to what Mercer (2000) calls exploratory conversation: students use each other's reasoning to modify their own thinking and at the same time they collaboratively build new ideas. In contrast, the transition probabilities depicted in Fig. 8 are similar to what Mercer (2000) calls accumulative conversation: students accept each other's ideas without negotiation and they construct shared knowledge by the accumulation of already known concepts. On the theoretical side, these results accentuate that effective learning is more likely to occur if cues help students spend less time for searching central domain concepts

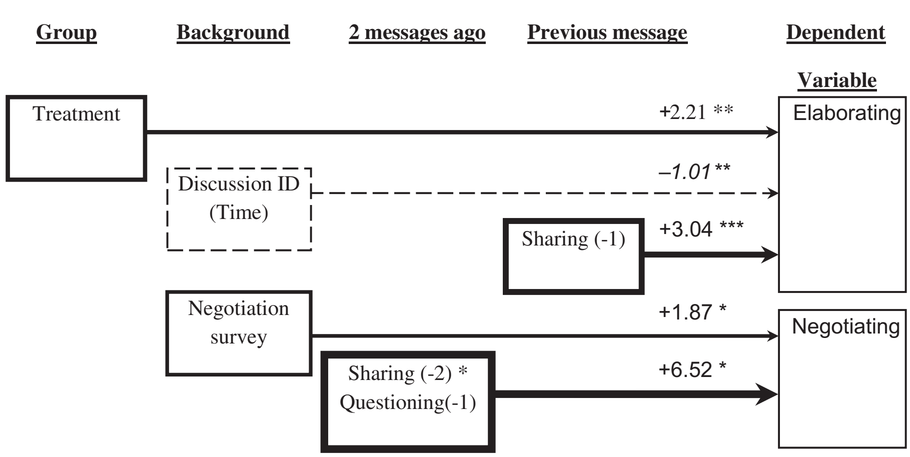

Fig. 8. Statistical discourse analysis findings $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 7
Selection ratio of task-relevant information from the last discussion topic.

Condition	Treatment group		Control group
	Instructor-based attention guidance functionality	Peer-oriented attention guidance functionality	
	Mean of 1st 5 topics	6th Topic	6th Topic
Frequency of student annotations focusing on challenging concepts	10.4	11	6
Total student annotations	14.2	16	21
Selection ratio of challenging concepts	73%	69%	29%

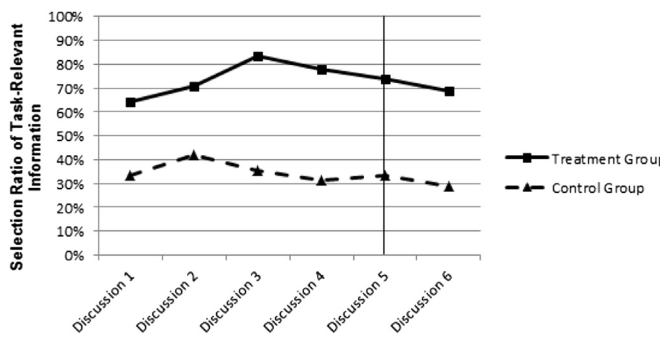

Fig. 9. Continuous trends in students' selection behaviors.

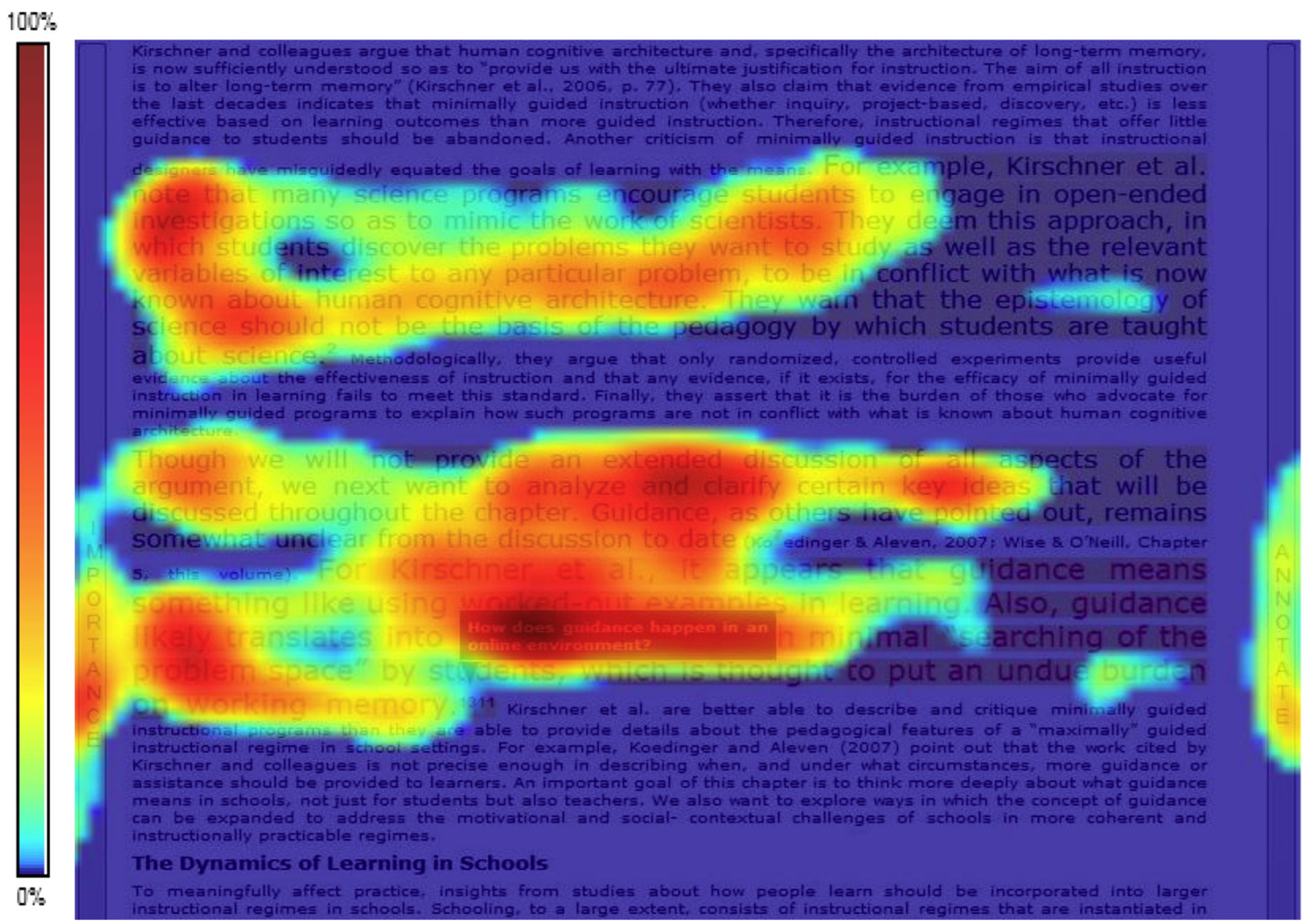

Fig. 10. Heat map for peer-oriented attention guidance functionality.

Table 8
Content analyses of first five discussions and the last discussion topic.

Messages		Attention guidance functionality				Control software system	
		Instructor-based		Peer-oriented			
		Mean	Proportion	Frequency	Proportion	Frequency	Proportion
Task-related	Sharing	13.2	0.30	15	0.32	13	0.34
	Questioning	10.4	0.24	13	0.28	6	0.16
	Elaborating	6.0	0.14	5	0.11	1	0.03
	Negotiating	4.6	0.11	6	0.13	2	0.05
	Producing	0.6	0.01	0	0.00	0	0.00
	Total task-related	34.8	0.80	39	0.84	22	0.58
Non task-related		8.6	0.20	8	0.17	16	0.42
Total		43.4	1.00	47	1.00	38	1.00

Table 9
Descriptive statistics and t-test results of the prior knowledge test.

	n	M	SD	95% CI
Treatment group	12	5.25	0.62	[4.90, 5.60]
Control group	12	5.08	0.67	[4.70, 5.46]

Note. CI = confidence interval.

and principles, which gives them more time to diagnose and revise challenging misconceptions (Renkl & Atkinson, 2007). Moreover, in line with Suthers et al. (2010) and Zemel et al. (2007), the statistical discourse analysis results showed that a message in a threaded discussion contributing to such an understanding can depend on a cumulative series of immediately preceding messages, specifically this common sequence: sharing (−2) → question (−1) → negotiation (0). Taken together, the important results at hand support the value of instructor-based attention guidance functionality in an open learning environment.

Third, this study found that after the treatment group students switched from an instructor-based to peer-oriented attention guidance functionality, they maintained their attention on challenging concepts from complex instructional materials, supporting the view that fading the system's support and shifting responsibility to students does not hinder these students' performance on this task. This finding extends the existing literature by showing that building scaffolding into software allows students to practice their knowledge in novel situations. Thus, we argue that building software tools that eventually fade support offers a natural solution to the fundamental problem of adaptive web-based learning system design (for an overview see Fischer, 2001). Moreover, within the scaffolding paradigm, peer-oriented attention guidance functionality highlights the fact that social software enables implicit learning processes in such a way that an individual student can benefit from the collective knowledge that is inherent in a collaboratively generated artifact (Kimmerle, Cress, & Held, 2010). Consistent with our theoretical perspective, the present finding suggests that the students in the treatment group internalized the instructor's assistance, though the results of this small sample on this small time interval must be interpreted cautiously.

8. Resulting conceptual framework

Drawing upon the theoretical framework and empirical results presented in our study, we will now propose a conceptual framework portrayed in Fig. 11. At the forefront of our conceptualization lies the distinction between shallow and deeper processing of text in open learning environments. On the one hand, students may stick to shallow processing of text when they gravitate toward familiar topics by sharing existing experiences and opinions that relate to and triggered by the topics in the text. This form of processing is generally easier for students and takes less effort. On the other hand, deeper processing or getting to the "heart" of a complex instructional material takes a lot of effort because students have to diagnose and revise challenging misconceptions by elaborating and negotiating ideas, similar to assembling a jigsaw puzzle where every participant contributes a part of a picture without comprehending the whole (see the discussion sample

Table 10
Descriptive statistics and t-test results of task complexity.

Discussion topic	Treatment group ($n = 12$)		Control group ($n = 12$)		t	p
	M	SD	M	SD		
Topic 1: the success or failure of constructivist instruction (weeks 2–3)	4.00	0.74	4.33	0.77	0.31	0.76
Topic 2: taking guided learning theory to school (weeks 4–5)	4.25	0.75	4.42	0.51	0.19	0.85
Topic 3: epistemology or pedagogy, that is the question (weeks 6–7)	4.33	0.49	4.5	0.52	0.10	0.92
Topic 4: the empirical support for direct instruction (weeks 8–9)	4.5	0.52	4.58	0.51	0.11	0.91
Topic 5: from behaviorism to constructivism (weeks 10–11)	3.92	0.79	4.00	0.74	0.08	0.94
Topic 6: beyond the fringe: building and evaluating scientific knowledge systems (weeks 12–13)	4.67	0.65	4.5	0.52	0.20	0.84

Note. Degree of freedom = 22. Task complexity survey utilized a six-point scale (1 = not at all; 2 = just a little bit; 3 = somewhat; 4 = pretty much; 5 = very; 6 = extremely).

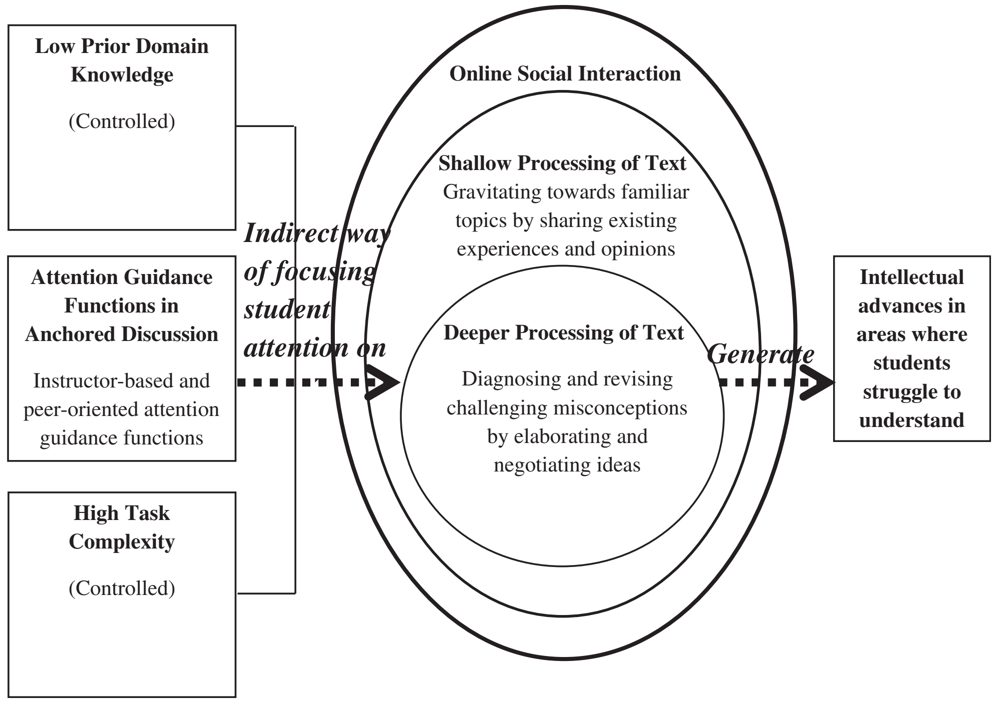

Fig. 11. Resulting conceptual framework.

provided in Table 6). Based on this distinction, we present shallow and deeper processing of text as nested levels in online social interaction. During a discussion, students may go from shallow to deep processing and vice versa. However, we have seen that often only a smaller portion of the total discussion focuses on deeper processing of text. It is this deeper processing, where students take on the hard task of struggling with a text's meaning and advance their understanding of it. In other words, the problem at hand is that in the educational practice of collaborative online literature processing (with low prior domain knowledge and high task complexity) students often do not engage in this deeper level processing. Our results demonstrate that the proposed attention guidance functionalities can afford an indirect focusing effect to students' deep processing of the text at hand.

9. Conclusion

The study reported in this article is part of an action design cycle in which we investigate the affordances and constraints of fundamentally social technologies for mediating collaborative knowledge construction and individual learning outcomes. As a third step in this endeavor, we provided valuable insights to researchers and teachers about the trajectory of transforming classrooms toward more collaborative knowledge construction environments. In sum, an overall principle drawn from this study is that instructor-based and peer-oriented attention guidance functionalities in an anchored discussion system prompt students to mindfully interact with or reflect upon the central aspects of complex instructional materials. Without guidance, regular online discussion appeared to be scattered, inefficient, and less focused on challenging concepts from complex instructional materials. This type of discussion is especially problematic when research on the effects of collaborative learning is highly inconclusive (see Kirschner et al., 2009; Phielix et al., 2010 for reviews) because when misconceptions remain undiscovered students fail to grasp important information (Engelmann & Hesse, 2011). In contrast, guided online discussion was more integrated, efficient, and focused on intellectual advances in areas where students struggle to understand. Two major implications can be derived from the findings of this study. First, students with low prior domain knowledge can benefit from guidance to carry out complex learning-tasks and learn from them. Second, building scaffolding into software can help students with low prior domain knowledge develop expertise. Tools such as the ones described in this article open a promising new perspective for designing and using software to scaffold learning.

As with all research, this study has a number of limitations. First, the present study had a small sample size, in part because content analysis and sequential analysis are labor intensive and time consuming. A larger sample size can increase the validity and generalizability of our findings. Second, this study focused on student's collaborative knowledge construction process. We did not examine individual learning outcomes developed from collaborative knowledge construction. Still, other studies have linked deep processing of instructional materials' central aspects with individual learning outcomes (see Eryilmaz, Van der Pol, et al. 2013 for an association between knowledge construction activities and individual learning outcomes). Third, it is unclear whether or not participants in the peer guidance condition would have maintained high quality discourse if the condition persisted over a series of discussions. Thus, more research is needed to assess the effects of peer-oriented attention guidance functionality over a long duration.

Many critical questions remain to be addressed under this theoretical framework as we design more advanced tools to scaffold students during online learning conversations. What are the relationships among different types of technology-enhanced scaffolds and how can we fade them to facilitate adaptive web-based systems? If students become dependent on technology-enhanced scaffolds, do they interact less with peers and instructors? We will examine these issues in our future studies.

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